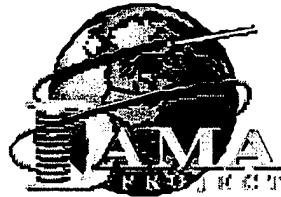


Demand Activated Manufacturing Architecture



An Introduction to USITC Enterprise Analysis

by

James K. Ostic
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Technology and Safety Assessment Division
Los Alamos National Laboratory
Los Alamos, NM 87545

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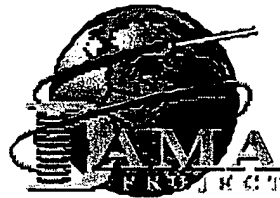
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This report was prepared by the DAMA Los Alamos Analysis Team. For Copies of this document, contact Jim Lovejoy, Textile/Clothing Technology Corporation [TC²], (919)380-2184, or Sue Watters, Los Alamos National Laboratory, (505)665-0639.

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Preface

The United States Integrated Textile Complex (USITC) consists of fiber, textile, apparel, and retail firms who manufacture and distribute natural and synthetic fiber products. In today's competitive global economy, USITC companies who team together to form supply chains require relationships which promote responsiveness to consumer demand, encourage business partnerships, and make effective use of resources. These supply chains, or "pipelines," are being analysed to improve time and cost performance.

Enterprise analysis is the application of analysis methods and simulation tools to predict integrated performance of these pipelines. Through the use of scenario analysis, various alternatives in pipeline coordination and configuration can be assessed. Simply put, the end result is to design the pipeline so that the product the customer demands is delivered, in the right place, at the right time.

In September 1996, industrial participants of the Demand Activated Manufacturing Architecture (DAMA) project completed the Phase I pipeline analysis study. The analysis identified opportunities to improve productivity and efficiency among five supply chain members, and proposed a generic modeling architecture and methodology that, if implemented, would identify actions necessary to improve supply-chain coordination among its members. The architecture and methodology are being pursued during the Phase II analysis, which is scheduled to be completed by the end of FY 1997. The goal of the Phase II analysis is to propose actionable recommendations to supply-chain members leading to a reduction of pipeline lead-time by 50%.

An Introduction to USITC Enterprise Analysis

Preface	i
1.0 Introduction.....	1
2.0 The 21st Century Competitive Environment	2
2.1 Market Challenges of Global Competition	2
2.2 Competitive Response within the USITC.....	4
3.0 Supply Chain Primer.....	7
4.0 Enterprise Modeling and Simulation.....	15
4.1 Pipeline Analysis.....	15
4.2 Phase I Pipeline Analysis	16
4.3 Phase II Pipeline Analysis.....	18
5.0 References.....	21
6.0 Glossary of Terms.....	24

List of Figures

1. Pipeline Sectors and Analysis Members.....	1
2. USITC Employment Levels are Projected to Continue to Decline	2
3. Fundamental Principles of Supply Chain Performance	8
4. Contributors to Pipeline Lead Time.....	9
5. Apparel Pipeline Represented as an Equivalent Liquid Pipeline System	10
6. Fabric Mills Offering Information Services to Sewn Product Customers.....	12
7. Improved Performance Emerges from a Properly Configured Pipeline Design	14
8. Required Capabilities for Supply-Chain Analysis.....	17
9. Phase I Pipeline Analysis Results	19

List of Tables

1. Hourly Wages of International Textile Workers.....	3
2. Principal Elements of Quick Response.....	5
3. Inventory Drivers and Actions Leading to Inventory Reduction	13

1.0 Introduction

The goal of The AMTEX Partnership™ is to strengthen the competitiveness of the U.S. integrated textile complex. AMTEX is a collaborative research and development program among the textile industry, the Department of Energy (DOE) and its weapons laboratories, and universities. The Demand Activated Manufacturing Architecture (DAMA) is the DOE-funded component of AMTEX. DAMA's objective is to demonstrate new business processes and tools necessary to compete in the electronic marketplace of the future.¹ A number of goals exist to focus the research and development efforts, including (1) improvements in pipeline business processes and (2) establishing and providing opportunities to implement an Internet-based marketplace.

A "pipeline" is defined in the DAMA project as fiber, textile, apparel, and retail companies that partner to manufacture and distribute apparel products. "Pipeline analysis" is the application of analysis methods and simulation tools to predict the integrated performance of these pipelines. Alternatives in pipeline coordination and configuration can be assessed through scenario analysis. Simply put, the end result is to design the pipeline so that the product that the customer wants is delivered in the right place and at the right time.

A rapid-response study was initiated in May 1996 to analyze the performance of a five-member textile pipeline. As shown in Fig. 1, the members of this pipeline are L. L. Bean® as the retailer, Cascade West Sportswear as the apparel maker, two textile makers (Glenn Raven Mills and Malden Mills), and DuPont as the synthetic fiber producer. This Phase I study, which was completed in September 1996, identified pipeline improvements resulting from improved forecasting methods and improved inventory and manufacturing policies.² The goal of the Phase II study is to define the actions necessary to reduce pipeline lead time by one-half.³

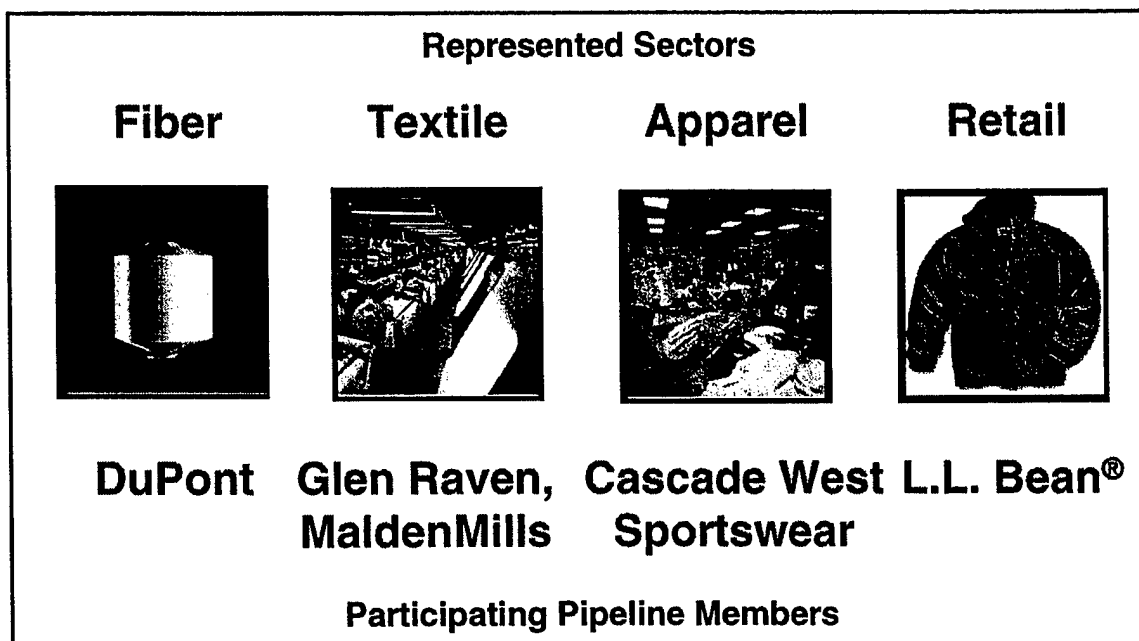


Fig. 1. Pipeline Sectors and Analysis Members.

2.0 The 21st Century Competitive Environment

The United States Integrated Textile Complex (USITC) is a vital part of the U.S. economy. The complex produces both natural and synthetic fibers and converts these fibers into products such as carpet and apparel. The USITC contributes some \$59 billion to the U.S. gross domestic product, an amount larger than the automobile industry and comparable to the aerospace industry in size. Recently, the USITC has seen a declining balance of trade and plunging net exports. For example, offshore apparel producers now manufacture one-half of the apparel sold in the U.S. retail market, and the trade imbalance from apparel accounts for roughly one-third of the total U.S. trade deficit.⁴

The industrial trends confronting the USITC are challenging: global competition from agile and responsive competitors, the necessity for regional partnering, advancing information and manufacturing technologies, and increasingly dynamic consumer demand. What can the textile industry do to thrive in this 21st century global competitive environment?

2.1 Market Challenges of Global Competition

If there is a single term that best represents the future of market competition for the USITC it is challenge. Recently, world leaders met at the annual meeting of the International Textiles Manufacturers Federation in Washington, DC, to review coming industrial trends. Dramatic market changes are anticipated; the key ones will be the increasing pace of global competition and the necessity of teaming with regional trading partners (such as in the Americas, Asia, and Europe).⁵ Global competition is expected to increase as U.S. and foreign retailers look overseas to build export markets, experience reduced export resistance in the form of quotas and tariffs, and use low-wage workers in developing countries for textile and apparel manufacture.

Job loss is viewed as the major indicator that the USITC is suffering from global competition. As shown in Fig. 2, employment levels in the textile and apparel manufacturing sectors decreased from 1.9 million in 1983 to roughly 1.6 million in 1994. An additional 70,000 jobs were lost between 1994 and 1995, and projections are predicting a continuing downward trend.⁶

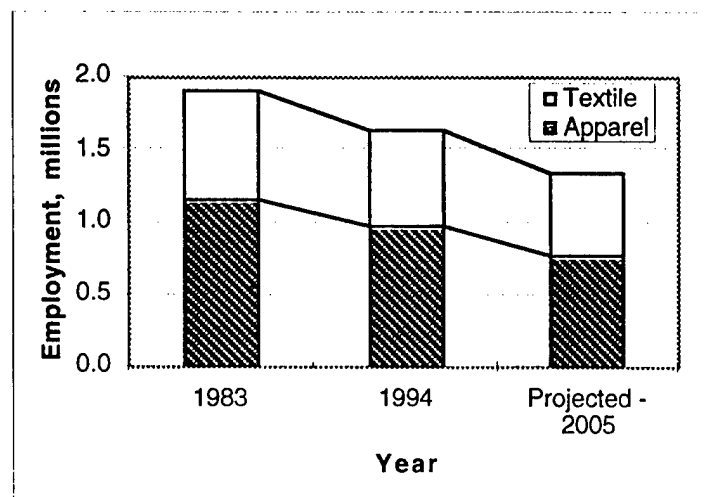


Fig. 2. USITC Employment Levels are Projected to Continue to Decline.⁶

There are many reasons for job loss, but the major reason is the competitive advantage of using low-cost foreign labor. Table 1 shows the cost advantage held by competitors who use international rather than domestic labor.

Table 1. Hourly Wages of International Textile Workers⁷

Location	Hourly Labor Rate
China	\$ 0.48
India	\$ 0.58
Mexico	\$ 3.40
Hong Kong	\$ 4.40
United States	\$11.89

Some key features of USITC job loss are illuminating. Employment levels in apparel are declining more rapidly than in those in textiles. Apparel is a more labor-intensive industry than textile and thus is more vulnerable to a labor cost differential. The textile industry consists of large industrial firms that have invested more heavily in capital improvements. In the 10 years before 1993, the capital investment in textiles averaged roughly \$1 billion per year as compared with an apparel investment that was roughly one-third less.⁶ As a result of the textile industry's higher level of technological maturity and historically higher investment levels in plants and equipment, this industry is more productive and less susceptible to low-cost offshore labor competition.

A detailed review of the employment statistics shows that the major share of job loss is occurring to the shop floor operators and laborers in both the textile and apparel industries. Of the 300,000 lost jobs projected to occur between 1994 and 2005, 5 of 6 are expected to come from this group.⁶ Only one small group is expected to increase in job number—the professional specialists involved in engineering and computer science, who will be expected to nurture those technology changes necessary to keep the industry competitive in the coming years.

Is there a solution to the projected job losses in the USITC? Employment level is the result of a very complex dynamic that operates within and between firms, industries, and economies.⁸ Competitive advantage is gained in the marketplace through product or cost differentiation and results in employment growth opportunities.⁹ A shift in demand to new and improved products generates higher labor demand. Cost reductions that result from process simplification, redesign, or automation tend to be labor saving. However, the resultant increase in profit from savings can be invested in technologies that lead to competitive advantage, improvement in market share, and ultimately growth in employment. The effect of these changes on employment is a function of the dependence of revenue generation at the firm, the success of the change, and how successfully this revenue is reinvested into growth opportunities for the firm.

Japan is facing challenges similar to those experienced in the U.S. A Japanese textile trade surplus of \$2.5 billion in 1982 eroded to a \$13.8 billion deficit in 1994.¹⁰ However, as the Japanese manufacturing base has shifted progressively offshore to China, the country has developed a global competitive strategy that invests in long-term viability through steady funding of research and development. Flexible, high-speed, and automated manufacturing

methods coupled with predictive capabilities in the development of fibers are examples of strategic technology that can be used to rapidly specialize products.

Although the trend within the USITC is to a much greater reliance on foreign manufacturing, moving to a foreign sourcing strategy should be undertaken only after a careful consideration of the complexities of the enterprise. USITC decision-makers should be fully aware of the true costs of operating an international pipeline.¹¹ Certainly, the need for coordination between supply chain partners becomes even more critical as the supply chain becomes more globalized. Coordination costs are higher for international supply chains. Communication across foreign boundaries often injects time lags because of the staggering of work hours across time zones. Foreign travel, foreign languages, and cultural differences in work policies all may impede insightful and responsive decision-making, which is critically needed for optimum pipeline performance.

The use of international supply chains requires pipeline members to carry more inventories and assume more risk. For the case of identical manufacturing capacity, lead times are longer for international pipelines because of longer transport distance. When ocean distances are involved, as in the case of Far East trade, ocean shipping may add roughly 3 weeks to pipeline lead time. To compensate for the longer pipelines, more finished good inventory must be carried at the retailer in the form of safety stock. Ocean shipments also are larger than corresponding highway freight shipments. These larger and slower ocean pipelines are less responsive to fast moving market conditions and require retailers to forecast farther in the future in developing manufacturing plans.

Retail analysis has shown that domestic quick-response (QR) strategies provide a cost advantage over importing. Earlier studies had indicated that QR was effective in increasing inventory turns, service levels, and resultant financial performance for product lines with shelf lives of 10 or fewer weeks; however, it is now realized that, with a 2-week apparel lead time, such strategies outperform importing, even with an 8-week shelf life.¹²

2.2 Competitive Response within the USITC

A number of industry-led initiatives have been attempted to improve the competitiveness of the USITC. The focus has been to develop techniques that provide improved responsiveness to the demands of the marketplace. These demand-driven approaches require improvements in information technology, sharing of critical data, and greater reliance on partners. Ultimately, the alliances that result seek to reduce the cost of doing business within the pipeline through gains in operational efficiency.

QR, continuous replenishment, and accurate response are initiatives that have gained favor.¹³ QR can be described as a business strategy to improve competitiveness through improvements in pipeline member technology and collaboration. Continuous replenishment (otherwise known as "vendor-managed inventory") is a QR modification in which the vendor, not the retailer, is responsible for replenishing inventory stock. "Accurate response" is a new approach to forecasting, planning, and production that builds on QR capabilities established within the USITC during the last decade. Accurate response seeks to improve supply chain performance sufficiently that manufacturers can postpone decisions regarding unpredictable products until forecasts can be validated with point-of-sale data.

The motivation to achieve these capabilities is compelling, including the following rationale to adopt QR.

- Linkage of pipeline members in a customer-focused partnership that shares critical information through state-of-the-art information technology
- Improved financial performance through increased sales, reduced markdowns and stockouts, and commensurate reductions in inventory levels and manufacturing lead times
- Substantial and supportive changes in business practices.

The principal elements of a firm performing under a QR charter are shown in Table 2. Adoption and use of advanced information technology allows QR firms to create pipeline linkages that are much more responsive than previous industrial partnerships. When information has been distributed throughout the pipeline, QR firms use advances in production and logistics technologies to manufacture and deliver products efficiently.

Table 2. Principal Elements of Quick Response¹⁴

Information Technology
Uniform product codes
Point-of-sales data tracking
Electronic data interchange
Continuous updating of consumer demand
Frequent orders
Computer automated product design
Infrastructure information network
Logistics
Frequent, small lot shipments
Just-in-time shipping policies
Pre-ticketing and drop shipment
Manufacturing
Flexible, short-run processing
High-speed manufacturing
Automated material handling
Rigorous quality control
Modular production concepts

The enabling technology of QR is the ability to rapidly and accurately acquire, handle, and transfer information. Three fundamental abilities are needed to gain from information technology¹⁵: (1) a standard uniform product code system to identify materials anywhere along the pipeline, (2) a standard electronic data interchange (EDI) standard for partners within the complex (and ultimately throughout the world), and (3) an information infrastructure network to conduct business. Information on consumer sales, manufacturing plans and available manufacturing capacities, and inventory levels are all examples of critical pipeline information that could be shared between partners.

To deploy advanced information technologies, supply chain members must overcome a number of challenges:¹⁶

1. There is a need to interface between firms that vary widely in information technology sophistication—from small apparel makers with single PC platforms to large progressive firms in fiber, textile, apparel and retail who possess a variety of sophisticated computer systems and networks.
2. Supply chain members require a number of services, including electronic file transfer, database access, and common software applications—all in proprietary data settings.
3. The ability to access information quickly is a necessity to partner across a large number of firms and to service increasing variety in product offerings.

Logistics is the process of enabling effective flow and storage of raw materials, in-process inventory, and finished goods within the pipeline. By using frequent, small-lot shipments and just-in-time shipping policies, the QR vendor can minimize the time materials reside in inventory. Individual firms have been successful in greatly reducing inventory within the pipeline by using lean manufacturing techniques, even at process facilities.¹⁷ Traditionally, process facilities such as fiber manufacturers have been reluctant to alter manufacturing practices because of a heavy investment in capital equipment. However, these facilities have found that a focus on materials handling and distribution systems has been successful in reducing work in process inventory, improving quality, and eliminating waste.¹⁸

Improvements in USITC manufacturing can be pursued among many fronts. Flexible, short-run processing results when processes are redesigned to allow for frequent product changeover. For example, in a recent analysis of woven-fabric producers, weaving preparation was identified as a bottleneck in small-lot-size processing.¹⁹ The analysis showed that holding a yarn inventory was an effective strategy because less capital is tied up with warp beam and fabric inventory. However, the analysis results are sensitive to the time required to manufacture a product and still meet required delivery dates.

Automation of material handling operations in the textile and apparel industries has been studied extensively.²⁰ USITC textile firms face two primary challenges to the introduction of automation technology: (1) extended payback periods are required to recoup investment in automation technology and (2) the older buildings that house textile factories (an average of 30 years old) are not amenable to automation.²¹ However, automation in textile and apparel firms has the potential to increase machinery efficiency and reduce associated labor. Combing, spinning lines, continuous yarn operations, and cutting and sewing are examples of processes to which automation may be applied.

In summary, the improvements required to achieve QR are many, including adoption of new and automated information technology, change in the fundamental methods of performing business, investment in rapid manufacturing technology, and achievement of aggressive quality levels in the product. Because of the expansiveness of QR, methods and tools are needed to chart the path from the configuration of today's supply chain to the preferred future configuration.

- What are the information, business, and technology leverage points along a supply chain that, if invested in, provide the best return?
- How can information be shared among supply chain partners to create the most value?
- What negotiation and compromise agreements should be established to create the most competitive supply chain alliances?

3.0 Supply Chain Primer

To fully understand the complexities of pipeline performance, one must look for the underlying structure and controls that exist within a supply chain. The supply chain system consists of a number of firms interconnected by material and information flows. As materials flow from fiber suppliers downstream through the chain through textiles and apparel, raw materials are processed or transformed into more functional and integrated products with higher economic value. Ultimately, the value added to a material is in its transformation from the raw material to a finished good. Materials are transported through appropriate distribution centers, where stocking policies may delay their flow. Ultimately, the products flow to the retail center, which distributes the product to the consumer.

“A structure is essential if we are to effectively interrelate and interpret our observations in any field of knowledge. Without an integrating structure, information remains a hodgepodge of fragments.”

Jay Forrester, *Principles of Systems*²²

To meet projected demands at retail, information flows upstream from retail in the form of forecasts and orders. However, there is a true co-flow of both materials and information—materials in the form of preseason samples also flow upstream through the supply chain and information on order status and shipping flow downstream as well.

The USITC consists of roughly 25,000 companies. Approximately 80% of these manufacture fabricated products; roughly 20% are textile manufacturers, and approximately 50 or so companies are large fiber producers. A typical fiber plant can manufacture about 1,000,000 pounds of fiber per day, which supports roughly 100 nominal textile plants. The textile plants, which nominally manufacture about 1,000,000 square yards of fabric per week, support roughly 4 average apparel manufacturers.

Because of the variability in size of any supply chain member, the number of products produced, the number of customers served, the number of suppliers relied on, and the dynamics of market demand, it is difficult to develop an all-encompassing supply-chain structure. Therefore, a generic architecture is required to analyze supply chains within the USITC. This generic structure, as proposed by Chandra,²³ includes three primary components.

- A structural component that represents the physical and logical systems within the supply chain, including manufacturing and business functions and characteristic material and information flows
- A control component that incorporates decision-making levels for both members and the supply chain group
- An optimization component that allows for the investigation of various alternatives

To fully understand the complexities associated with supply-chain performance, the above-mentioned architecture coupled with computer-based simulation are being developed. However, general insights can be gained by viewing the supply chain through qualitative performance guidelines. For this reason, five fundamentals of supply-chain performance have been collected and synthesized from literature and DAMA-funded work at the Los

Alamos National Laboratory. These fundamentals of supply-chain performance are listed in Fig. 3 and are discussed in the remainder of this chapter.

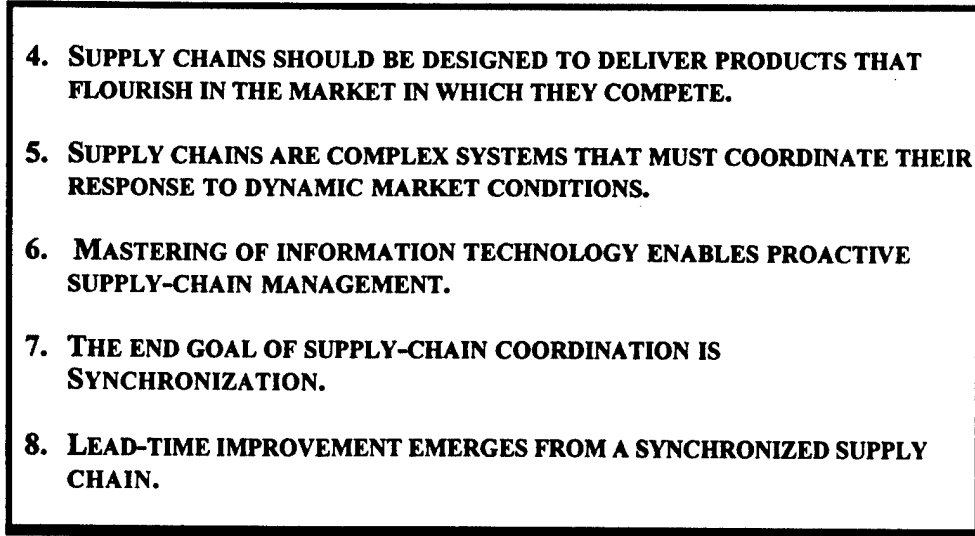
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- 4. SUPPLY CHAINS SHOULD BE DESIGNED TO DELIVER PRODUCTS THAT FLOURISH IN THE MARKET IN WHICH THEY COMPETE.**
 - 5. SUPPLY CHAINS ARE COMPLEX SYSTEMS THAT MUST COORDINATE THEIR RESPONSE TO DYNAMIC MARKET CONDITIONS.**
 - 6. MASTERING OF INFORMATION TECHNOLOGY ENABLES PROACTIVE SUPPLY-CHAIN MANAGEMENT.**
 - 7. THE END GOAL OF SUPPLY-CHAIN COORDINATION IS SYNCHRONIZATION.**
 - 8. LEAD-TIME IMPROVEMENT EMERGES FROM A SYNCHRONIZED SUPPLY CHAIN.**

Fig. 3. Fundamental Principles of Supply Chain Performance.

1. Supply chains should be designed to deliver products that flourish in the market in which they compete.

In a recent article in the Harvard Business Review,²⁴ Marshall Fischer poses the question, "What is the right supply chain for your product?" Fischer suggests that supply chain members consider the nature of their products before they devise an integrated supply chain design. Just as in developing a manufacturing strategy, a supply chain can be configured to emphasize speed, quality, efficiency, variety, cost, accuracy, or a combination of these attributes. The author makes his case by comparing supply chain design differences between functional and innovative products.

A functional product has a long life cycle, a low number of product variants, a stable demand, low stockout rates, and relatively long lead times. The key is to design the functional product supply chain to compete on fiber, textile, and feature performance at low cost. Because product demand and design are fairly stable, the supply strategy is to promote high equipment use, low inventory levels, and efficient distribution systems. On the other hand, an innovative product has the opposite attributes: short product life cycles, high variety, large forecast errors leading to larger stockout rates, and, by necessity, shorter lead times to compete in the dynamic marketplace. Because the product demand is variable, the innovative product supply chain must respond to an uncertain marketplace by investing aggressively in lead-time reduction strategies, must be able to engage manufacturing capacity on short order, and must be able to deploy significant buffer stocks.

Pipeline lead time is defined for a product as the cumulative time required from the initial order of fiber feedstock materials to the deliver of the fiber-containing product to the retail customer. As shown in Fig. 4, pipeline time is composed of order fulfillment and transport time terms at each pipeline sector. Order fulfillment time can be decomposed into time to place and process an order and setup and manufacturing times. Further decomposition of times can be assessed as discussed in Chap. 4. In addition, inventory times along the pipeline do exist and should be added to the pipeline terms shown.

Because the end product uses a number of component stock keeping units (SKUs), pipeline time will vary by fiber material. However, it is useful to identify the pipeline material that has the longest pipeline time. Without consideration of inventories, this material possesses the critical path on the integrated product schedule. The processes that limit the material flow along the pipeline are called bottlenecks. An hour saved at these critical path bottlenecks will result in an hour saved in pipeline time.

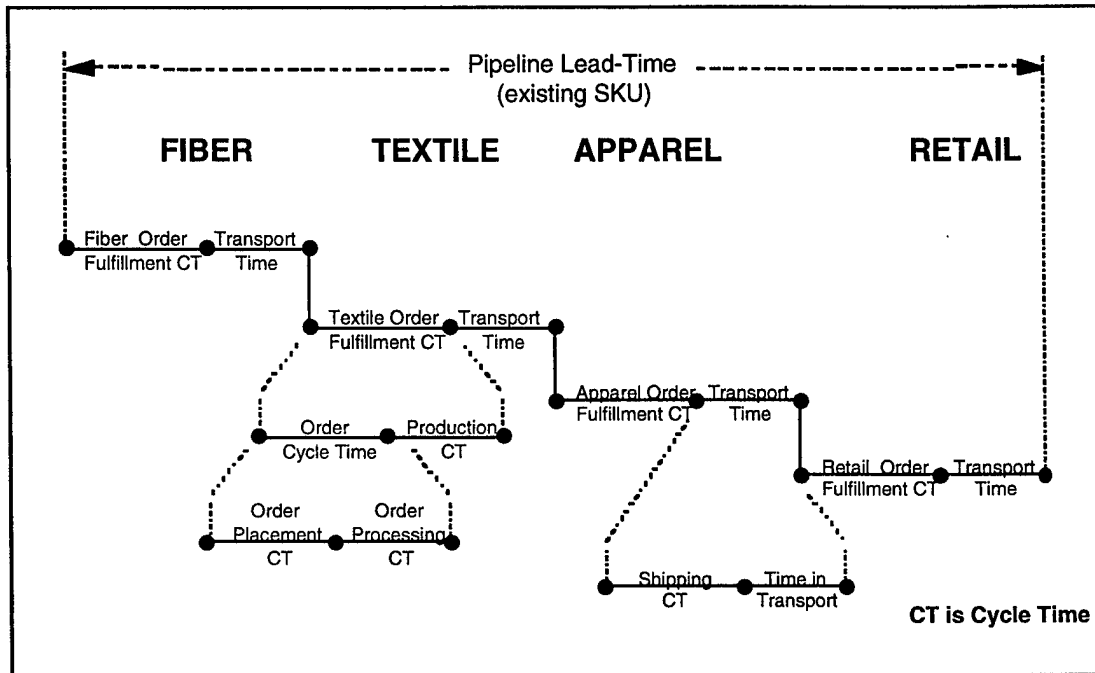


Fig. 4. Contributors to Pipeline Lead Time.

2. Supply chains are complex systems that must coordinate their response to dynamic market conditions.

An apparel manufacturing and retailing pipeline can be represented by an equivalent liquid pipeline system. The goal of a liquid system is to provide the appropriate flow of product to meet the customer demand. In a liquid system, pumping speed and pressure drop along the pipeline controls the flow rate. In the case of the textile pipeline, the capacity and availability of the manufacturing and logistics processes dictates product velocity. Liquid inventories are held in tanks, whereas textile inventories are held as finished good or raw material inventories. The textile pipeline is filled with work-in-process inventory to enable the continuous operation of the manufacturing operations just as liquid in the pump and lines fill the liquid pipeline. Figure 5 is a schematic of the liquid pipeline model of the textile complex.

The challenge is to have the pipeline deliver quickly, efficiently, and accurately. To do so in the apparel sense is to possess the ability to quickly produce those styles that are selling in the marketplace. Therefore, the pipeline must deliver products with high product velocity, yet retain the ability to quickly switch between various styles.

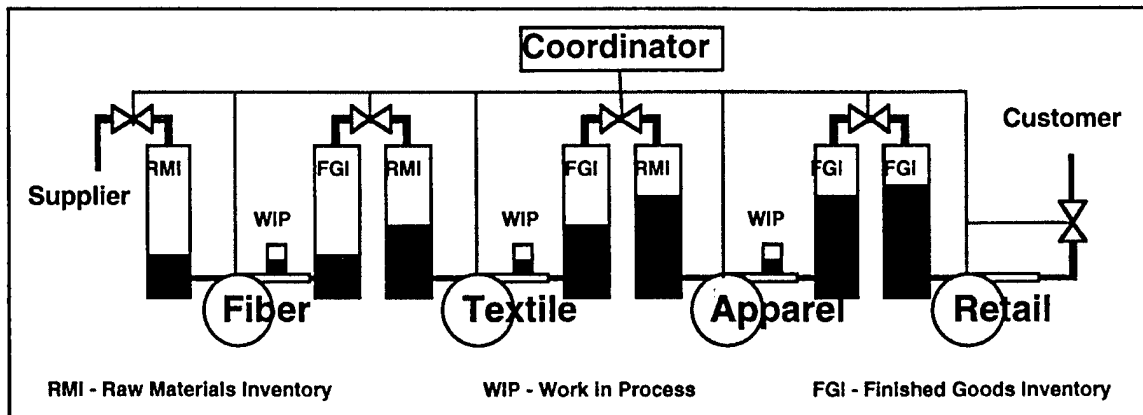


Fig. 5. Apparel Pipeline Represented as an Equivalent Liquid Pipeline System.

The ability to create products faster and with increasingly flexible manufacturing processes has resulted in an unprecedented number of SKUs to manage. For example, a recent study has shown a 63% growth rate in the number of SKUs within an existing product line between the years 1988 and 1992.²⁵ Contributing to this change were commensurate changes in SKUs introduced and dropped from product lines:

- a 56% growth rate in the number introduced into a product line and
- a 48% growth rate in the number dropped from a product line.

The same study identified a consistent increase in the number of selling seasons per year for all fashion categories (basic, fashion-basic, and fashion). In another study, Richardson analyzed the challenge of competing in the dynamic fashion apparel market.²⁶ In this market, which is characterized as hypercompetition, retail firms compete by introducing fashion in an attempt to capitalize on short-term differences between offerings. However, such product differentiation is not sustainable because competitive advantage is “difficult to create and nearly impossible to sustain.”

The conclusion is apparent. As the number and mix of SKUs changes more rapidly over shorter and shorter seasons, the products being offered possess less of a marketing track record, and the uncertainty in forecasting their demand increases. Put another way, the product lifetime is getting progressively shorter for the goods that are being sold.

For a pipeline to be respond proactively to market forces, the information system that links its partners must provide timely and accurate information. By its very nature, a pipeline may produce distorted information to upstream partners. Order information, as it progresses along the pipeline, must be protected from oscillations and variations, commonly called the “bullwhip effect”.²⁷ In a traditional supply chain, demand information is received discretely as orders from downstream customers are received and processed. The timing of these orders may be periodic because of monthly or biweekly planning runs. In addition, these orders may be altered by the use of forecasting algorithms by each member, such as exponential smoothing.

The use of discounting or special promotions by the supply chain provider may produce surges in demand that can be read incorrectly by upstream suppliers or may drive oscillatory patterns in orders as customers stockpile goods. Finally, downstream customers may hedge orders for items in short supply to increase the probability of supply during shortages. These effects exaggerate the amplitude and variability of the supply chain signal, an effect that becomes magnified the farther from the source that the information is processed.

The authors propose a set of coordination responses between supply-chain members to counteract the bullwhip effect.²⁷

1. Develop a single forecast that can be propagated upstream from downstream customers.
2. Make more frequent orders through the use of EDI.
3. Stabilize pricing at retail to prevent oscillatory ordering patterns.
4. Eliminate hedging on orders by allocating supplies in high demand periods based on historic order quantities.

3. Mastering of information technology enables proactive supply chain management.

Information technology, or the application of computers, software, and telecommunications, has been proposed as a fundamental element in a new industrial engineering discipline.²⁸ But information technology is successful only when it is used to support new and better ways of conducting business.²⁹ Therefore, for information technology to be successfully implemented, it must integrate with processes and lead to automation of information services. Such business uses of information technology include

- providing for rapid learning in forecasting by electronic sensing of market conditions and updating of computer models,
- rapidly communicating critical information with supply-chain partners,
- coordinating plans with supply chain partners by considering alternative supply-chain group strategies, and
- rapidly executing plans using communication channels established through EDI and production control systems.

Examples of information to be shared using EDI include forecasts, inventory levels, production plans, and internal movements of materials. Figure 6 shows the results of a recently conducted survey of textile manufacturers. Roughly five out of six textile companies offer EDI. Three-quarters of those questioned provide shared forecasting data. Half of the textile firms offer electronic invoicing and electronic fund transfer.

Adoption of EDI, just like any new technology, does not guarantee business success. Firms should migrate to EDI only after developing a coherent strategy. The proper role of EDI can be developed through planning, as expressed by Holland, Lockett, and Blackman.³⁰

Consider your suppliers: The current trend in industry is to create very strong links with a limited number of suppliers to ensure the reliability of supply necessary to practice lean retailing. If you are a member of a large and complex supply chain (which is naturally more vulnerable to poor information quality), an emphasis on accuracy in communication is warranted.

Consider your internal processes: EDI permeates throughout the whole of the organization and allows suppliers to fill more frequent and smaller orders. However, an opportunity of more significance may be the ability to promote rapid development in the environment where product lifecycles are decreasing significantly.

Consider your customers: Consider providing information as a product of the value chain. In the future, the use of electronic commerce may allow consumers within the supply chain to encourage competition and variety among suppliers.

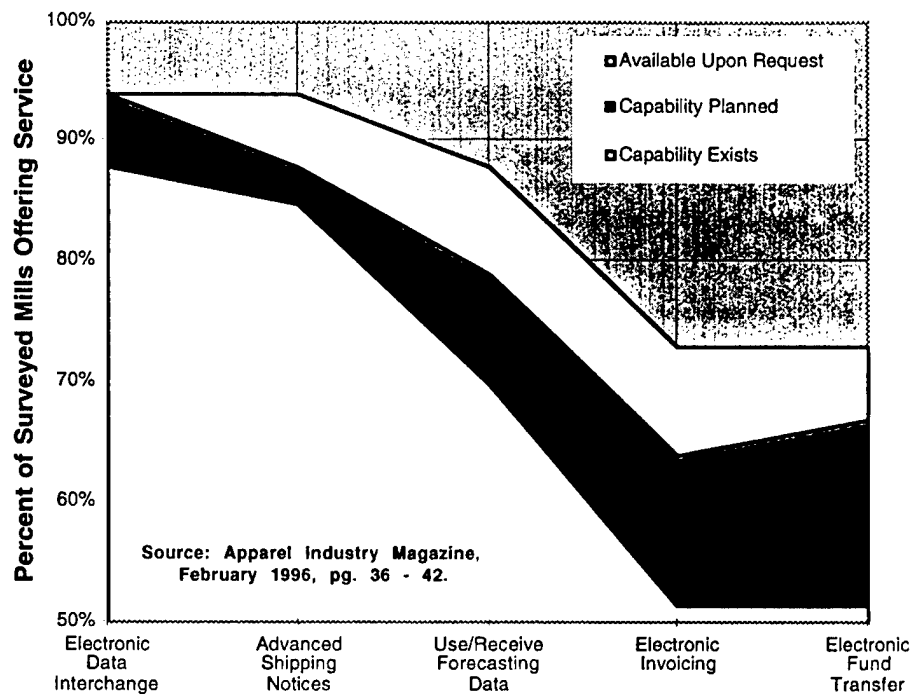


Fig. 6. Fabric Mills Offering Information Services to Sewn Product Customers.³¹

Information technology allows proactive supply chain management. Table 3 is an example of the use of information to manage inventories. Because the market is dynamic in its demand preferences, significant uncertainty must be managed by retailers to deliver timely products to the marketplace. A retailer faces not only uncertainty in product demands but also uncertainty in raw materials supply.³² Typically, supply chain members manage uncertainty through the use of material inventories—storing raw materials, operating with work-in-process materials, or stockpiling finished goods. There are other ways of managing supply chain uncertainties as well; for example, long-term contracts may be put in place to ensure production capacity at critical times.³³

“Learning to operate with significantly lower stocks of raw materials and finished goods is no simple matter because so many new disciplines must permeate the organization.”³⁴

Inventories are carried in the pipeline for a number of reasons.³⁴ The mismatch between timing of an expected demand and the constancy of manufacturing supply requires retailers to stockpile goods. Safety stocks are necessary to guard against uncertainty both in demand from downstream customers and in supply from upstream suppliers. Uncertainty in demand has a number of root causes: dynamic market conditions, the maturity of the product, style, price, season length, etc. Supply uncertainties are caused by fluctuation in dedicated capacity and yield of manufacture, variation in the quality of product, and range of distribution performance. Some inventory results from the design of the manufacturing processes; cycle stock results from manufacturing batch sizes and the need to transport goods between work stations results in inevitable work in process inventory. Inventory also may be used to decouple adjacent workstations, allowing decisions to be made independently from upstream or downstream processes.

Table 3. Inventory Drivers and Actions Leading to Inventory Reduction

Inventory Type	Root Cause of Inventory	Actions Leading to Inventory Reduction
Anticipation	<ul style="list-style-type: none"> • Demand is seasonal 	<ul style="list-style-type: none"> • Reserve manufacturing capacity • Improve forecasting • Reduce lead time
Order Stock	<ul style="list-style-type: none"> • Efficiency degrades with small batch sizes 	<ul style="list-style-type: none"> • Reduce setup & changeover times
Decoupling Stock	<ul style="list-style-type: none"> • Product flow is segmented 	<ul style="list-style-type: none"> • Simplify flow path • Co-locate critical operations
Safety Stock	<ul style="list-style-type: none"> • Product lifetimes are short • Demand is uncertain • Supply is uncertain 	<ul style="list-style-type: none"> • Improve forecasting • Improve lead time • Quickly access manufacturing capacity
Work in Process	<ul style="list-style-type: none"> • Intermediate products are allowed • Raw materials are stockpiled 	<ul style="list-style-type: none"> • Eliminate storage locations • Simplify flow path • Synchronize operations

What information technology will be needed to compete in the future? In the future, supply chains will act as competing entities. A 21st century corporation will be able to form global linkages within supply chains.³⁵ A central feature of the electronic marketplace is the ability to quickly sense changes in market conditions and respond to them with agility; therefore, the information technology of tomorrow includes the ability to accurately monitor and sense market opportunities through the use of data mining techniques. Ultimately, there is the need to vector information technology towards electronic commerce.

4. The end goal of supply chain coordination is synchronization.

The end goal of supply chain coordination is synchronization, or each member acting in ways that are appropriately timed with the actions of other pipeline members. An example of a synchronized supply chain is a perfectly run relay race in track, where each runner transfers the baton at exactly the time the next runner in the race comes up to speed. For example, the retailer places an urgently needed order for a certain style. The order then is filled by members in the pipeline using strategically held inventories and high-velocity manufacturing processes; the hand-offs of materials in the pipeline occur between members so that the flow of materials throughout the pipeline is continuous to satisfy the need. That is, the "flow" of materials along the pipeline is managed. The information feedback system of a synchronized system has been referred to analogously as a global positioning system with real-time feedback providing for mid-course correction of direction.³⁶

A supply chain can evolve to a synchronized state if the following conditions are met:³⁷

1. Data are shared between trading partners.
2. Communication between partners is rapid.
3. System events, changes, or exceptions are triggers for proactive feedback.
4. All activities within the supply chain are monitored.

It is interesting to note that in a recent analysis of the effect of modular production on apparel manufacturing, the coordination element among team members was identified as the key to improving performance.³⁸ The critical coordination elements include the group's ability to coordinate work, attack bottlenecks, resolve conflicts, jointly solve problems, and improve the integrated process. These coordination elements are identical to those needed for the supply chain group to achieve synchronized performance.

5. Lead time performance emerges from a synchronized supply chain.

A synchronized supply chain works to ensure that customer service goals are met at retail, including selling at higher margins, at competitive pricing, and with higher quality. Three major elements must be integrated to achieve these goals.

1. Business information systems must be designed so that a seamless, but integrated, member infrastructure is established. The rapid dissemination of critical information across member boundaries allows for accurate and rapid planning and execution.
2. Production and distribution technology continues to evolve in the USITC. Through use of high-leverage technologies, the supply chain member can manufacture products that differentiate themselves from those of the competition. The practice of synchronization and reduction of non-value-added activities on the manufacturing floor allows efficient and rapid fabrication to meet the needs of continually evolving markets.
3. Finally, cooperative decision-making is necessary to consider improvements in the supply-chain system rather than in the isolated member. The need is to view the pipeline members as a group and make the decision-making process a global, not local, one. Using this process will result in a more accurate, responsive, and efficient pipeline—ultimately leading to pipeline lead time improvement. This integrative strategy is shown in Fig. 7.

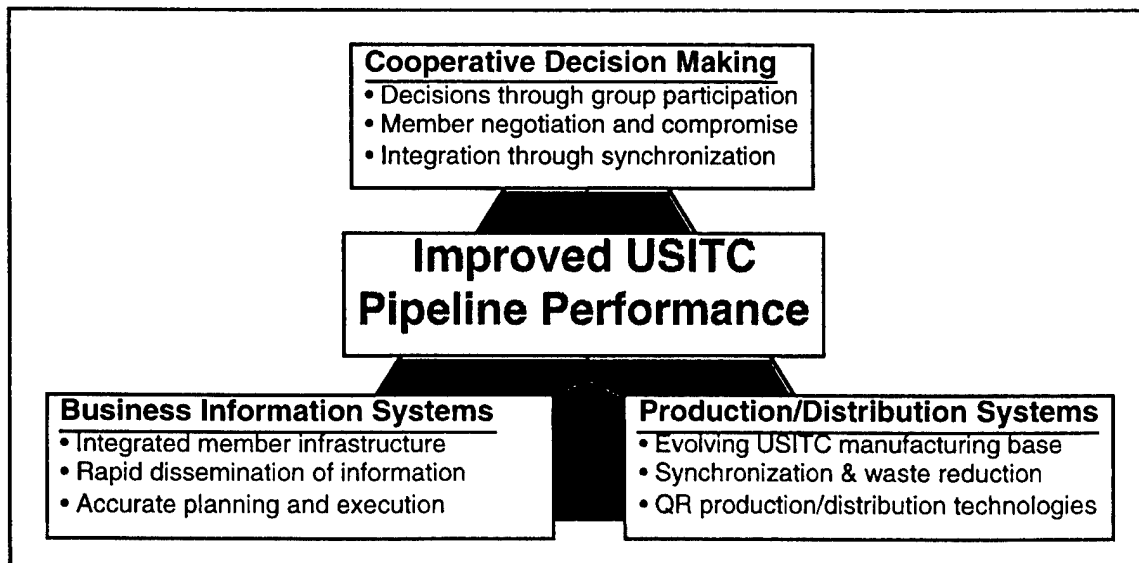


Fig. 7. Improved Performance Emerges from a Properly Configured Pipeline Design.

4.0 Enterprise Modeling and Simulation

Generally, an enterprise is a unit of economic organization or activity. We further define an enterprise as "those activities that are required to develop and deliver products and/or services to a customer." Specifically, an enterprise includes a number of functions and operations such as purchasing, manufacturing, marketing, finance, engineering, and research and development. The enterprise of interest is those corporate functions and operations necessary to manufacture current and potential future variants of a product. In the case of supply chains, the enterprise of interest includes the members of the pipeline who team together to manufacture and deliver the commercial product.

The term "enterprise model" is used in industry to represent differing enterprise representations with no real standardized definition. Because of the complexity of enterprise organizations, a vast number of differing enterprise modeling approaches have been pursued across industry and academia.³⁹ Enterprise modeling constructs can focus on manufacturing operations and/or business operations; however, a common thread in enterprise modeling is the inclusion of information technology assessment.⁴⁰ For example, the use of networked computers to trigger and receive replacement orders along a material supply chain is an example of how information technology is used to coordinate manufacturing operations within an enterprise.

Enterprise modeling and simulation allows the opportunity to assess the pipeline and propose change in it. Change can take place in a process, procedure, or organization within the pipeline. An enterprise initially may be analyzed using a mathematical or logical model representation. A flow chart of the processes necessary to manufacture and assemble a product is an example of a logical enterprise model. As more dynamic representations are required, a simulation model is constructed that allows the enterprise analyst to rapidly exercise a number of "what-if" scenarios using a computer program. Enterprise simulation analysts can focus their efforts on a wide variety of disciplines, a sampling of which includes information technology, business and manufacturing process engineering, organizational framework analysis, and human resource use. The goal is to exercise the "as-is" enterprise as it exists today and then postulate and test a "to-be" enterprise of the future.

4.1 Pipeline Analysis

Pipeline analysis is the application of analysis methods and simulation tools to predict the integrated performance of supply chains within the USITC. The appropriate goals for pipeline analysis were stated years ago by Jay Forrester in a discussion of the benefits of dynamic simulation models.⁴¹ Such goals are to

- aid in the understanding of the enterprise (in this case the pipeline),
- act as a useful guide to judgment and intuitive decisions, and
- help to establish desirable policies.

As mentioned earlier, a supply chain is a collaboration of partners who attempt to maximize their wealth by the manufacture of goods and provision of services. Management of the risks within the system is necessary. One of the best ways of managing or reducing risk is by generating system scenarios and then testing them.⁴²

As a supply chain system becomes more complex, for example, from the addition of members, the dynamic response of the system becomes less predictable without the use of dynamic models. These resultant dynamic effects are usually subtle; such models can provide

a means to explore their causes and what can be done to improve the system performance as a whole.⁴³

The role of pipeline analysis is to support a decision-making process. Because decision-making naturally implies the reallocation of resources, supply chain analysis ultimately is directed to a goal of change in the system. However, basing such decisions on model output makes sense only if the activities that are modeled support the goals affected by the decisions. Such activities are typically those that currently are ignored by today's modeling tools, including the following.

- Sharing supply and demand information at the appropriate level
- Deciding how to share a scarce resource
- Using negotiation and compromise mechanisms to achieve synchrony in a supply chain
- Determining a fair way to share risk
- Making goals explicit for multiple levels of responsibility
- Using optimization as a means to achieve process improvement both locally and globally in the supply chain.

This is not to say that such activities cannot be modeled—they can. It is simply that they are not in the commonly available tools at this time.⁴⁴ The activities require a large amount of functionality already to be defined and working so that they can be layered on top of the defined manufacturing processes.

In general, any tool that supports supply chain analysis must build on capabilities that are required for supporting manufacturing analysis. However, the scope of supply chain analysis requires that even more functionality be represented and exercised to achieve an appropriate level of analysis. In general, these requirements include more complete and extensive cognitive capabilities, often realized as forecasting functions, scheduling functions, flexible inventory management schemes, optimization routines, rule-processing to emulate decision-making (negotiation and compromise), and explicit representation of goals and objectives.⁴⁵ Figure 8 shows the building block approach necessary to develop synchronous modeling capabilities.

4.2 Phase I Pipeline Analysis

Initial efforts in pipeline analysis were focused on opportunities to improve productivity and efficiency in a five-member pipeline. We model the pipeline as composed of members who interact individually both as providers and consumers and have the potential to interact as a group. The pipeline members must cooperate to integrate their operations. Pipeline analysis architecture and methodology have been developed to investigate the potential of this cooperation to improve the pipeline performance.

During the Phase I analysis, it was demonstrated through a simulation analysis that improvement can result from integrating accuracy in forecasting with the appropriate inventory replenishment strategy. In 1996, the effort was to identify, assess, and mitigate the root causes of inventory buildup within the pipeline. For example, to anticipate highly seasonal demand and uncertainty in demand and supply, L. L. Bean[®] and its apparel makers carry additional inventory. For the pipeline manufacturers, inventory is carried as work-in-process, cycle stock because of continuous processes and decoupling stock such as griegre fabric.

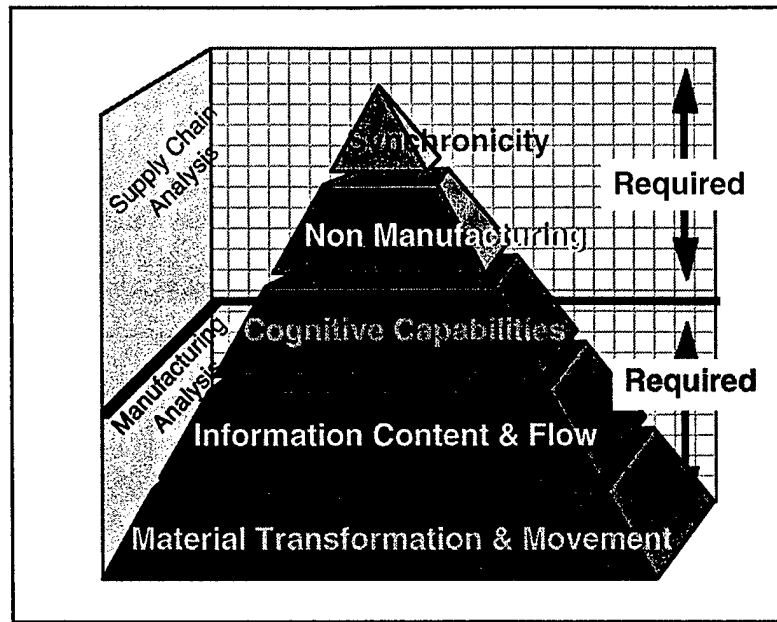


Fig. 8. Required Capabilities for Supply-Chain Analysis.

A supply chain architecture is a hierarchical representation of the business and manufacturing processes within the pipeline. The architecture consists of material flows, either at the process or activity level, business flows following the order life cycle, and decision-making models with the ability to make coordinated decisions at the pipeline group or individual member level.²³

The pipeline analysis methodology is a seven-step process. The first four steps focus on representation of the “as-is” pipeline; the last three steps analyze various “to-be” pipeline scenarios. Costing, scheduling, and multi-attribute parameter decision-making are modeled in the analysis. Examples of key industrial metrics include first service level, lost sales, profit per unit produced, and number of inventory turns per year.⁴⁶

The Phase I pipeline analysis used a warm-up jacket distributed through catalog retail by L. L. Bean®. The fiber used in the supplex outer shell is manufactured at DuPont in Seaford, Delaware, using the continuous polymerization process. This material is shipped to Glenn Raven Mills in North Carolina where, at three separate divisions, the fiber is texturized and woven and the fabric is finished. Supplex fabric is shipped to the cut-and-sew manufacturer in Seattle, Washington, for assembly. Polartec inner fleece from Malden Mills in Lancaster, Pennsylvania, is also sewed-in at this time. All of L. L. Bean®’s current distribution is from its warehouses in Freeport, Maine. Transportation distance for these materials sums to nearly 10,000 highway miles. Logistics improvements within the pipeline can be implemented.⁴⁷ Figure 9 provides a schematic of major materials flows within the pipeline.

As shown in Fig. 9, the jacket has a highly seasonal demand pattern: 80% of sales of this item occur in a 6-month time frame. To meet anticipated demand, L. L. Bean® must commit early for manufacturing capacity—roughly a third of the orders are committed by the start of the calendar year and roughly one-half of the orders are committed by the beginning of May. Fall catalog drops begin in mid-July. At this time, L. L. Bean® collects the necessary information to revise demand projections and correct production orders. From the retailer perspective, a more responsive, reliable, and accurate supply chain would help pipeline members maximize the profits during the heavy buying season.

The pipeline manufacturers have individual unit operations or activities such as processing, inspection, and setup. When this activity-based representation of pipeline was analyzed, it was found that

- the pipeline consisted of 180 separate individual activities,
- roughly 30% of these activities by number were manufacturing steps that added value to the product, and
- the rest of the activities are non-value-added (e.g., setup, inspection, storage) that could be improved through methods engineering.

An analysis of times that material is resident at the member companies shows that the apparel manufacturer bears the burden of carrying excess inventory to compensate for the uncertainty in retail demand and the lack of speed in manufacturing response. When combined with the textile manufacturer, these two members contribute about three-quarters of the residence time of materials in the pipeline.

Of the total time in the system, roughly 20% actually is consumed in manufacturing processes that add value to the product, such as continuous polymerization fiber production at DuPont; texturizing, weaving, and dyeing at Glenn Raven Mills; and cutting and sewing at Cascade West. The rest of the time, the material is sitting in raw material or finished good inventories or is being moved, stored, or prepared as work-in-process inventory.

A static analysis was completed during Phase I; the analysis assessed the effect of improved forecasting, inventory control, and management policies. Fourteen variations in forecasting methods were investigated, with the last method improving on the traditional month-forward planning basis used at L. L. Bean® by a factor of 3. When this forecasting improvement was coupled with a coordinated replenishment schedule, a significant improvement in inventory turns results at the retailer. This analysis used a rather coarse simulation in which individual members' production operations were aggregated. A more detailed manufacturing and business representation of the pipeline is being developed; in this representation, we can disaggregate the pipeline into individual manufacturing, inspection, and transportation activities.

A simulation model was developed using the *ithink*™ performance modeling system. This model represented the firms in the supply chain as individual entities with raw material and finished good inventories. The process- and activity-level representations of manufacturing technologies were missing, but after incorporating the inventory management and improved forecasting methods developed in the static analysis, the pipeline system showed improvements in first service level, lost sales, and profit per unit and showed significantly increased inventory turns.

4.3 Phase II Pipeline Analysis

The Phase II analysis objective is to show that a cooperative model can improve pipeline performance by integrating and synchronizing manufacturing and business operations. Our near-term focus is to identify the root causes of carrying inventory in member companies and investigate the potential of improving supply chain performance through coordination policies.



Our current efforts are in building simulation models that can model critical information flows necessary for coordination. Three major components will be used in the development of the model: (1) an inventory manager; (2) a production manager; and (3) a coordination manager. The inventory manager identifies the quantity and the timing of ordering. The production manager coordinates the material transformation within the member company managing the logistics function. Finally, the coordination manager is responsible for capacity planning and production scheduling within the member company. In addition, the coordination manager must coordinate production planning among the members of the supply chain group.

Discrete event simulation models are being constructed to meet the needs of the Phase II analysis to identify where lead time improvements can be made and to assess the effect of lead time improvement on the integrated performance of the supply chain. A reduction of lead time can reduce the cost of waste in the system by postponing decisions to manufacture until better information is gathered on the sales of the product line.

This pipeline architecture is ultimately traceable to the DOE's nuclear weapons complex. The Complex operates at much lower throughputs with a much more specialized product; however, there are members within the Complex who must interact to form a supply chain, and even though the performance metrics of the supply chain differ in emphasis, coordination mechanisms are needed to synchronize its performance. Requirements for this analysis and a Los Alamos test case are being developed.

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6.0 Glossary

The definitions listed below have been compiled from the sources listed in the reference section.

Activity-Based Costing. A procedure that allocates all costs (direct as well as indirect) to the activity of manufacturing.

Computer Integrated Manufacturing. The use of computers to design products, develop production plans, control manufacturing operations, and complete essential business activities.

Coordination. The process by which an entity reasons about its actions and the anticipated actions of others to ensure that the group acts in a coherent manner.

Cybercorp. A corporation that senses and reacts in real time to changes in environment, competition, and customer demand.

Decision. An allocation of resources.

Electronic Data Interchange. The exchange of information across organizational boundaries using information technology.

Enterprise. Generally, a unit of economic organization or activity. Essential activities that are required to develop and deliver products and/or services to a customer.

Hypercompetition. A heightened state of competition in the marketplace, characterized by rapidly changing styles and short product lifetimes.

Information Technology. Equipment, applications, and services used by organizations to deliver data, information, and knowledge.

Logistics. The process of planning, implementing, and controlling the efficient, effective flow and storage of raw materials, in-process inventory, finished goods, services, and related information from the point of origin to the point of consumption for the purpose of conforming to customer requirements.

Manufacturing Lead Time. The time from the commitment to manufacture a product to the time the product is acquired by a customer.

Model. In the context of enterprise modeling, a logical and/or mathematical representation of an enterprise.

Pipeline. A number of supply chain partners who produce fibers, textiles, and textile-related products and distribute these products through retail.

Productivity. The quantity of product produced over a certain time period normalized by the resource(s) required.

Product velocity. The rate at which a product flows through a pipeline.

Raw Materials Inventory. The quantity of input materials in storage necessary to support continued manufacturing operations.

Resources. Reusable and non-reusable entities (equipment, labor, information, materials) that are required to complete an enterprise-related task.

Simulation. A numerical exercise of a model to determine the effect of various inputs on the corresponding predictive outputs.

SKU. Stock keeping unit.

Supply Chain. A society or network of autonomous business entities formed to solve a common business problem. Commonly, member facilities that join together to convert materials to useful products before selling and distributing them to customers.

Synchrony. A state of balance or harmony existing between separate organizations.

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